Exam in
SSY305 Communication Systems

Department of Electrical Engineering

Exam date: June 10, 2022

Teaching Staff

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Material Allowed material:

- Chalmers-approved calculator.
- L. Råde, B. Westergren. Beta, Mathematics Handbook, any edition.
- One A4 page with your own handwritten notes. Both sides of the page can be used. Photo copies, printouts, other students' notes, or any other material is not allowed.
- A paper-based dictionary, without added notes (electronic dictionaries are not allowed).

Students are required to solve the exam problems individually. Cooperation, in any form or with anyone, is strictly forbidden.

Grading A correct, precise and well-motivated solution gives at most 12 points per problem. An incorrect answer, unclear, incomplete, or poorly motivated solutions give point reductions to a minimum of 0 points. No fractional points are awarded. Answers in any other language than Swedish or English are ignored.

Solutions Are made available at the earliest on **June 10 at 20:00** on the course web page.

Results Exam results are posted on Canvas no later than **June 27**. The grading reviews will be on **June 29** (remotely via ZOOM) according to a process that will be explained in the course webpage.

Grades The final grade of the course will be decided by the project (maximum score 46), quizzes (maximum score 6), and final exam (maximum score 48). The project and exam must be passed (see course-PM for rules). The sum of all scores will decide the grade.

Total Score	0–39	40–68	69–79	≥ 80
Grade	Fail	3	4	5

PLEASE NOTE THAT THE PROBLEMS ARE NOT NECESSARILY ORDERED BASED ON THEIR DIFFICULTY

Good luck!

1. Let's assume to have a systematic block code for error detection when transmitting frames over a noisy channel. A frame is represented by a codeword formed as follows: $\mathbf{c} = \begin{bmatrix}\mathbf{d} & \mathbf{q}\end{bmatrix}$ where $\mathbf{d} = \begin{bmatrix}d_0 & d_1 & d_2\end{bmatrix}$ are the information bits and $\mathbf{q} = \begin{bmatrix}q_0 & q_1\end{bmatrix}$ are the parity bits. The list of codewords used for transmission are the following:

	$d_0 d_1 d_2$	$q_0 q_1$
c_1	0 0 0	1 1
c_2	0 0 1	1 0
c_3	0 1 0	0 0
c_4	0 1 1	0 1
c_5	1 0 0	0 1
c_6	1 0 1	0 0
c_7	1 1 0	1 0
c_8	1 1 1	1 1

The channel introduces independent bit errors with probability p.

(a) Is $\mathbf{c}$ a linear block code? Motivate. (2p)

(b) Suppose the noisy channel works at rate $R = 100$ [Mbit/s]. Compute the value of the information bit rate when $p = 0$. (2p)

(c) What is the maximum number of bit errors that this block code is guarantee to detect? Motivate (4p)

(d) Assume that the transmitted codeword is c_5. Compute the probability that an undetected frame error might occur when $p = 10^{-4}$. (4p)

Solution Problem 1

(a) According to the definition we discuss in class, a block code $\mathbf{c}$ is linear if

$$c_k \oplus c_l = c_j \in \mathbf{c}, \forall c_k \in \mathbf{c}, \forall c_j \in \mathbf{c}$$

Take now $c_1 \oplus c_2$, as an example. The result is [00101] which is not a codeword. For this reason $\mathbf{c}$ is not a linear block code.

(b) Out of 5 bits in a frame only 3 are information bits. The information bit rate can be computed as :

$$R_i = \frac{3}{5} \cdot R = 0.6 \cdot 100 \cdot 10^6 = 60 \text{ [Mbit/s]}.$$

(c) To compute the minimum number of bit errors that can be detected we need to compute the value of the minimum distance of the code. Since the code is not linear we have to compute the distance between each codeword pair and then check what the minimum value is.

	$c_i \oplus c_j$	*distance*
$c_1 \oplus c_2$	0 0 1 0 1	2
$c_1 \oplus c_3$	0 1 0 1 1	3
$c_1 \oplus c_4$	0 1 1 1 0	4
$c_1 \oplus c_5$	1 0 0 1 0	2
$c_1 \oplus c_6$	1 0 1 1 1	4
$c_1 \oplus c_7$	1 1 0 0 1	3
$c_1 \oplus c_8$	1 1 1 0 0	3
$c_2 \oplus c_3$	0 1 1 1 0	4
$c_2 \oplus c_4$	0 1 0 1 1	3
$c_2 \oplus c_5$	1 0 1 1 1	4
$c_2 \oplus c_6$	1 0 0 1 0	2
$c_2 \oplus c_7$	1 1 1 0 0	3
$c_2 \oplus c_8$	1 1 0 0 1	3
$c_3 \oplus c_4$	0 0 1 0 1	2
$c_3 \oplus c_5$	1 1 0 0 1	3
$c_3 \oplus c_6$	1 1 1 0 0	3
$c_3 \oplus c_7$	1 0 0 1 0	2
$c_3 \oplus c_8$	1 0 1 1 1	4
$c_4 \oplus c_5$	1 1 1 0 0	3
$c_4 \oplus c_6$	1 1 0 0 1	3
$c_4 \oplus c_7$	1 0 1 1 1	4
$c_4 \oplus c_8$	1 0 0 1 0	2
$c_5 \oplus c_6$	0 0 1 0 1	2
$c_5 \oplus c_7$	0 1 0 1 1	3
$c_5 \oplus c_8$	0 1 1 1 0	3
$c_6 \oplus c_7$	0 1 1 1 0	3
$c_6 \oplus c_8$	0 1 0 1 1	3
$c_7 \oplus c_8$	0 0 1 0 1	2

The minimum value of the distance is 2. This means that the code is guaranteed to be able to detect all the single bit error patterns.

(d) We have an undetected frame error if after the occurrence of two or more bit errors we received a valid codeword. When transmitting [10001] the following error patterns can happen with probability:

$c_i \oplus c_j$	*Error pattern*	*Probability*
$c_5 \oplus c_1$	10010	$p^2 \cdot (1-p)^3$
$c_5 \oplus c_2$	10111	$p^4 \cdot (1-p)$
$c_5 \oplus c_3$	11001	$p^3 \cdot (1-p)^2$
$c_5 \oplus c_4$	11100	$p^3 \cdot (1-p)^2$
$c_5 \oplus c_6$	00101	$p^2 \cdot (1-p)^3$
$c_5 \oplus c_7$	01011	$p^3 \cdot (1-p)^2$
$c_5 \oplus c_8$	01110	$p^3 \cdot (1-p)^2$

The probability that an undetected frame error occurs is the sum of the probabilities of all these possible events:

$$p^4 \cdot (1-p) + 4p^3 \cdot (1-p)^2 + 2p^2 \cdot (1-p)^3 = 1.9 \cdot 10^{-8}$$

2. Consider a cellular system where two stations (i.e., STA1 and STA2) communicate with a base station BS. The stations are placed 15 km from BS. The propagation speed is 3×10^8 m/s.

   Suppose STA1 starts transmitting a packet of duration $T_p = 1\,\text{ms}$ at time $t = t_{1,\text{TX}} = 0$. STA2 becomes ready to transmit at some time $t_{2,\text{R}} \geq 0$. Depending on the medium access protocol, STA2 will transmit its packet at some time $t_{2,\text{TX}} \geq t_{2,R}$.

   (a) Let us assume that the stations are placed 300 m from each other, and that unslotted ALOHA is used. For what values of $t_{2,\text{R}}$ will the packets from STA1 and STA2 collide at BS? (2p)

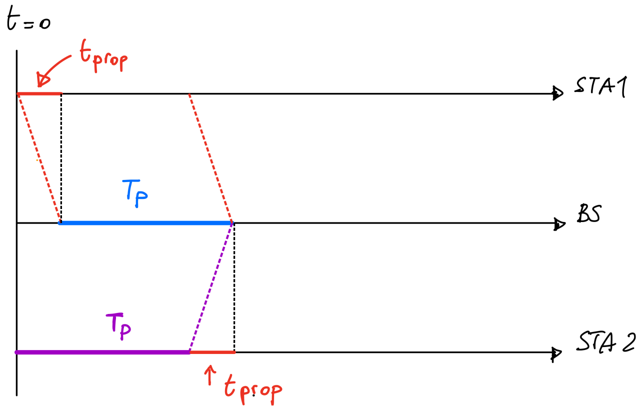
   (b) Repeat Part (a) assuming that CSMA is used. Assume that carrier sensing is perfect and instantaneous. (2p)

   (c) Repeat Part (a) and (b) when the stations are placed 30 km apart. (4p)

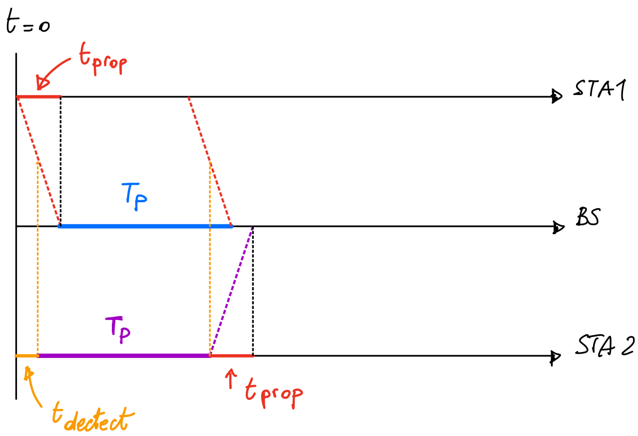
   (d) Assume that STA1 and STA2 generate, on average, G frames per frame duration and that the ALOHA protocol has a system throughput S (measured in frames/(frame duration)) that can be modeled as $S = G\exp(-2G)$. Derive the value of the best achievable system throughput (measured in frames per second units) (4p) (*Hint*: you can consider G as a variable that can be tuned to maximize throughput.)

Solution Problem 3

(a) If STA1 transmits at $t = 0$ the packet will reach BS after a time equal to t_{prop}. BS will complete the reception of the packet transmitted by STA1 at time $t = t_{prop} + T_p$. We will have a collision at BS as long as $0 \leq t_{2,R} < T_p$ (see figure below, not in scale), where $T_p = 1\,\text{ms}$.



(b) With CSMA, STA2 will monitor the medium to sense transmissions from other stations. When STA1 starts transmitting STA2 will sense the transmission after a time equal to $t_{detect} = \frac{300}{3\times10^8} = 1\,\mu\text{s}$. We will have a collision at BS if $0 \leq t_{2,R} < t_{detect}$ (see figure below, not in scale).



(c) Let us assume now that STA1 and STA2 are 30 km apart. The conclusion reached in Part (a) will not change. The relative distance between the stations does not impact the result for ALOHA, i.e., we will have a collision at BS as long as $0 \leq t_{2,R} < T_p$, where $T_p = 1\,\text{ms}$.

This is not the case when we use CSMA. The new value of t_{detect} is now $t_{detect} = \frac{30000}{3\times10^8} = 100\,\mu\text{s}$. We will have a collision at BS as long as $0 \leq t_{2,R} < t_{detect}$.

(d) Assuming the ALOHA protocol considered in this problem has a system throughput S that can be modeled as $S = G\exp(-2G)$ [frames/(frame duration)], we can derive the following.

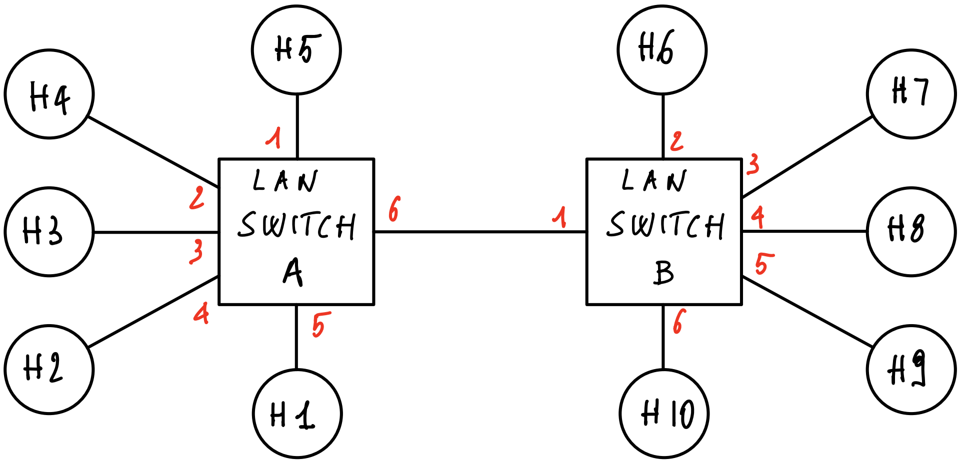
$$\frac{dS}{dG} = (1-2G)e^{-2G}$$
$$\frac{dS}{dG} = 0 \rightarrow G = 1/2$$

With $G = 1/2 \rightarrow S_{\max} = \frac{1}{2}e^{-1}$ [frames/frame duration].

The frame duration is $T_p = 1\,\text{ms}$. The maximum achievable throughput can then be computed as:

$$R = \frac{S_{\text{max}}}{T_p} = 183.9 \text{ [frames/s]}.$$

3. Consider the following network in which 10 hosts (round nodes in the figure) are connected together via two LAN-switches (transparent bridges). The transmission cables (marked with bold lines) support 1 Gbit/s full duplex transmission and are each 500 m long. The propagation speed in the cables is $c = 2c_0/3$, where $c_0 = 3\times10^8$ m/s. The switches operate in store-and-forward mode. That is, an incoming frame is completely received before it is forwarded to the corresponding output port. Assume that the processing times in the switches and hosts are negligible. The number next to the transmission cable attachment is the LAN switch port number.



(a) Suppose the only data traffic is from H1 and H10. We define the transmission time as the time it takes from when the first bit of the transmitted packet leaves H1 until the final bit of the transmitted packet has reached H10. What is the transmission time for a 1500 byte long packet? (4p)

(b) Suppose we want to implement a link-layer ARQ protocol. If the ACK packets are 25 byte long, what is a good value for the timeout to avoid unnecessary packet re-transmission for the scenario assumed in part (a)? Motivate. (4p)

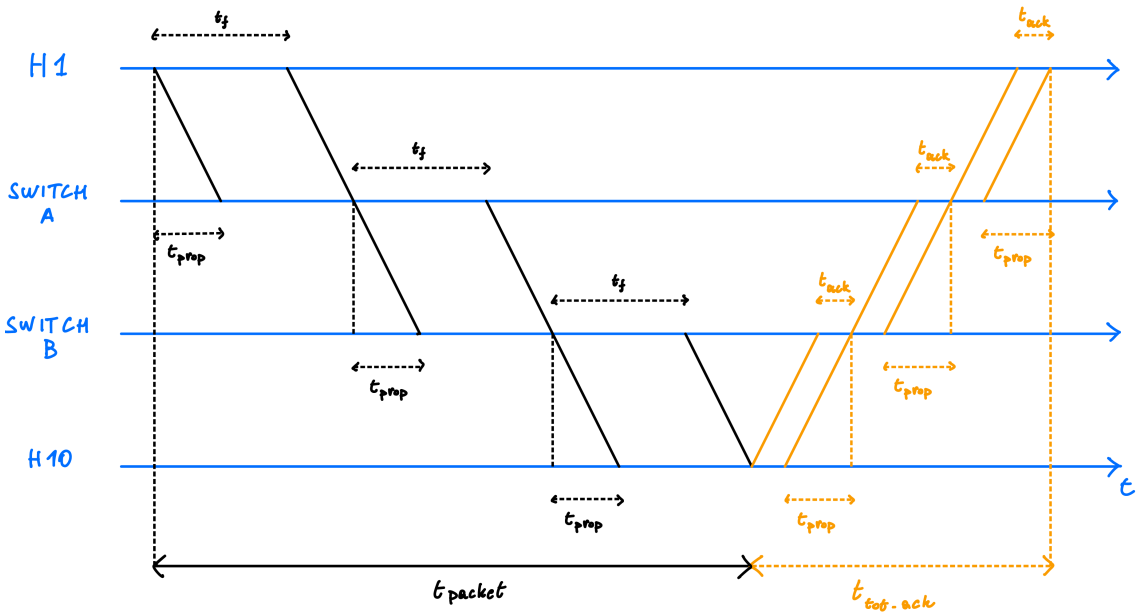
(c) The routing tables in the LAN switches has the form

Destination Address	**Output Port**
a	x
b	y
$\vdots$	$\vdots$

That is, when the LAN switch receives a frame with destination address a it forwards the frame to port x, etc. Suppose the LAN switches are powered up at time $t = 0$, which implies that the routing tables are empty. Explain how the tables in LAN switch A and B change for each of the following transmissions. Assume that backwards learning is used. (4p)

Time t [s]	**Source Host**	**Destination Host**
1	1	6
2	4	1
3	6	7
4	4	3
5	6	1

Solution Problem 3



(a) According to the time diagram above the transmission time of a packet from Host H1 to H10 can be computed as:

$$t_{packet} = 3 \cdot t_{prop} + 3 \cdot t_f$$

Where t_{prop} is the propagation time and t_f is the time required to transmit a frame (i.e., either at one of the Hosts or at the LAN switch) with a rate R.
Assuming:

$$R = 1 \cdot 10^{-9}[bit/s]$$
$$n_f = 1500 \cdot 8 = 12000$$
$$t_f = n_f/R = 12 \cdot 10^{-6}[bit/s]$$

and

$$l = 500[m]$$
$$c = 2 \cdot 10^{8}[m/s]$$
$$t_{prop} = l/c = 2.5 \cdot 10^{-6}[s]$$

As a result we have

$$t_{packet} = 3 \cdot t_{prop} + 3 \cdot t_f = 7.5 \cdot 10^{-6} + 36 \cdot 10^{-6} = 43.5 \cdot 10^{-6}[s]$$

(b) In order to avoid unnecessary re-transmission the timeout (t_{out}) need to be set at least equal to the time needed to receive the first ACK. Looking at the time diagram we can derive:

$$t_{out} \geq t_{packet} + t_{tot\_ack} = t_{packet} + 3 \cdot t_{ack} + 3 \cdot t_{prop}$$

where

$$t_{ack} = 25 \cdot 8/R = 0.2 \cdot 10^{-6}[s]$$

and

$$t_{out} \geq 43.5 + 0.6 + 7.5 \rightarrow t_{out} \geq 51.6 \cdot 10^{-6}[s]$$

(c) At $t = 1$, H1 sends a frame to H6. The frame is received by Switch A on port 5. The forwarding table of Switch A is empty, so the info about H1 is saved together with the ID of the port the frame came from (i.e., 5). Switch B does not know anything about H6 either, so the frame is sent out to all the ports of the switch (i.e., 4, 3, 2, 1, and 6). Switch B receives the frame at port 1, its table is empty, so it saves the information about H1 being reachable on port 1. The frame is also sent out to all the other ports of Switch B (2, 3, 4, 5, and 6).

Switch A	
Destination Address	**Output Port**
$H1$	5

Switch B	
Destination Address	**Output Port**
$H1$	1

At $t = 2$, H4 sends a frame to H1. The frame is received by Switch A on port 2. At Switch A, the info about H4 is saved together with the ID of the port the frame came from (i.e., 2). Switch A knows that H1 is reachable via port 5, so the frame frame is sent to that port only. No changes in the table of Switch B.

Switch A	
Destination Address	**Output Port**
$H1$	5
$H4$	2

Switch B	
Destination Address	**Output Port**
$H1$	1

At $t = 3$, H6 sends a frame to H7. The frame is received by Switch B on port 2. At Switch B, the info about H6 is saved together with the ID of the port the frame came from (i.e., 2). Switch B does not know anything H7, so the frame is sent out to all the ports of the switch (i.e., 1, 3, 4, 5, and 6). Switch A receives the frame at port 6, it saves the information about H6 being reachable on port 1. The frame is also sent out to all the other ports of Switch B (1, 2, 3, 4, and 5).

Switch A	
Destination Address	**Output Port**
$H1$	5
$H4$	2
$H6$	1

Switch B	
Destination Address	**Output Port**
$H1$	1
$H6$	2

At $t = 4$, H4 sends a frame to H3. Switch A already knows about H4 and its Output Port, but does not know anything about H3. The frame is sent out to all the ports and received by Switch B on port 1.

Switch A	
Destination Address	**Output Port**
$H1$	5
$H4$	2
$H6$	1

Switch B	
Destination Address	**Output Port**
$H1$	1
$H6$	2
$H4$	1

At $t = 5$, H6 sends a frame to H1. Switch B knows about H6 being reachable via port 2 and Switch A knows about H6 being reachable via port 1. No changes in the tables.

4. (a) Suppose Alice want to communicate confidentially with Bob using asymmetric cryptography. Which key does Alice use to encrypt her messages to Bob? Choose from Alice's private key, Alice's public key, Bob's private key, or Bob's public key. Motivate. (2p)
   (b) Explain the purpose of the demodulator in Shannon's communication model. (1p)
   (c) What is the purpose of using square-root Nyquist pulses for PAM transmission? (1p)
   (d) Describe the service provided by the TCP protocol in the TCP/IP model. (2p)
   (e) When we consider Automotive control applications, what are the pros and cons of using Ethernet? (2p)
   (f) Consider a protocol a layer-n protocol. Which data unit has the most number of bits, a n-PDU or a n-SDU? Motivate. (2p)
   (g) Why is collision detection not used in WiFi? (2p)

Solution Problem 4

(a) Alice will use Bob's public key to encrypt messages to Bob, and Bob will use his private key to decrypt the message. The public keys are not secret. Hence these cannot be used for decrypting messages that are supposed to be confidential (since anyone can use the public key). Alice cannot use her public key to encrypt since no one, including Bob, should know her private key. Hence, the only possibility is for Alice to encrypt with Bob's public key (which is known to Alice). To summarize, everyone can encrypt messages to Bob, but since only Bob knows the Bob's private, only Bob can decrypt the message.

(b) The purpose of the demodulator is to convert the received analog signal to decisions on the transmitted bits.

(c) To avoid Inter Symbol Interference (ISI) between the transmitted symbols. The result is a bandwidth-limited signal.

(d) TCP provides a reliable, connection-oriented, full-duplex, byte-based stream service

(e) Pros: Ethernet is a well-established standard, used in many applications, and provides good flexibility and bandwidth. Cons: copper is expensive, so sensitive to wiring costs. Copper is also susceptible to electromagnetic interference and compatibility, so specific attention is required to address these aspects.

(f) A layer n-SDU is encapsulated into the layer n-PDU. As a result, a layer n-PDU has (in general) more bits than a layer n-SDU.

(g) If a station is transmitting over the wireless medium, it is hard to detect if other stations are transmitting simultaneously. This is because the difference between the transmitted and received power might be very high in Wi-Fi systems. As a result, sensing the medium while transmitting is not practical.